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(54) Displacement transducers

(57) A capacitative displacement transducer in which the electrodes 12, 14 are formed by a pressure die-casting process enabling mass production of transducers having similar characteristics to very close tolerance.

In one embodiment, two die cast elements comprise cylindrical plates (12a-12c, 14a-14c) which are axially tapered to provide a mould release angle, the angles of taper being complementary so that the faces of the plates remain mutually parallel.

FIG.6

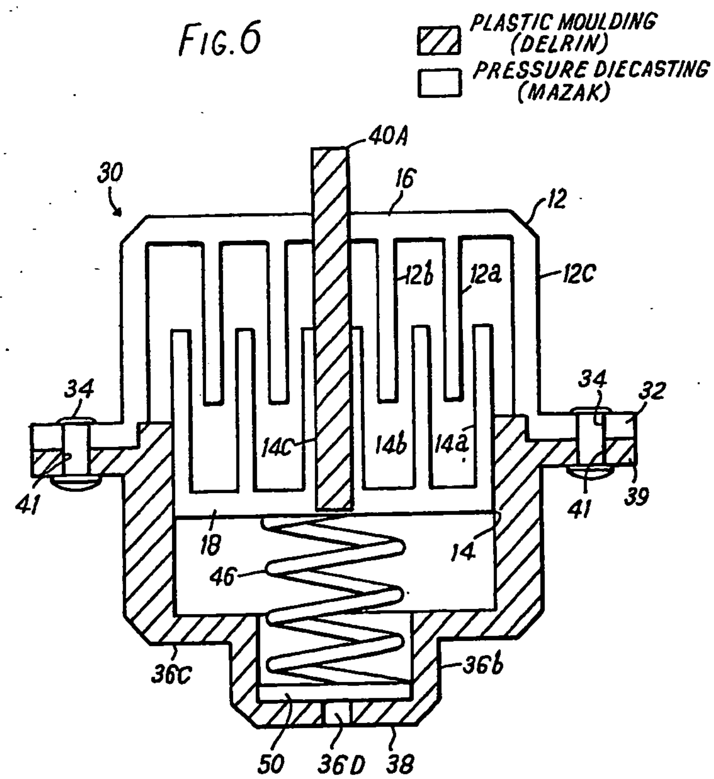

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FIG. 1

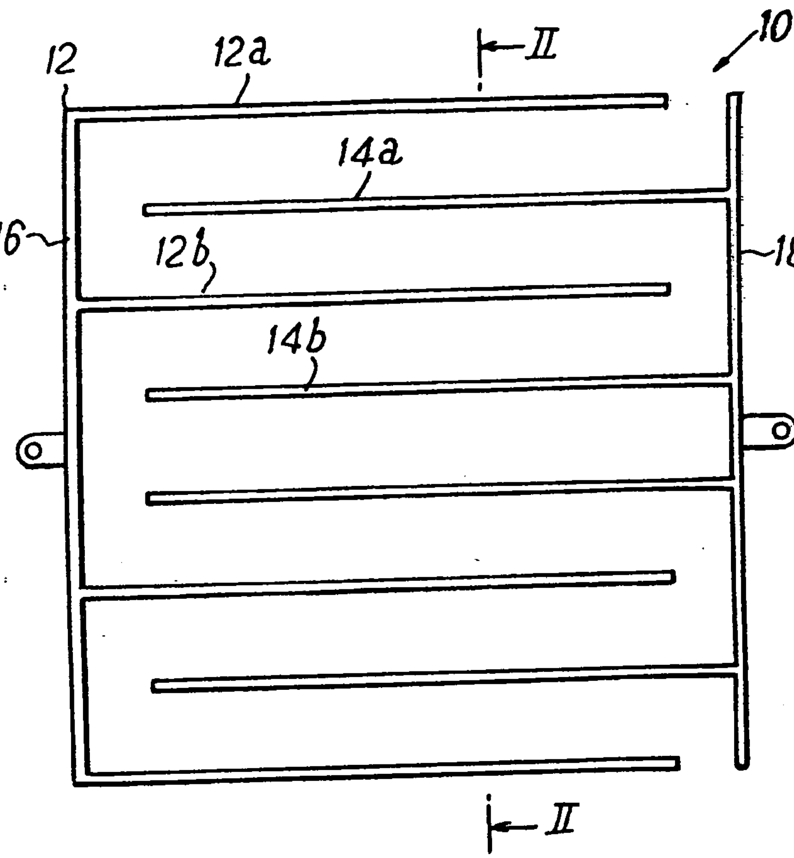
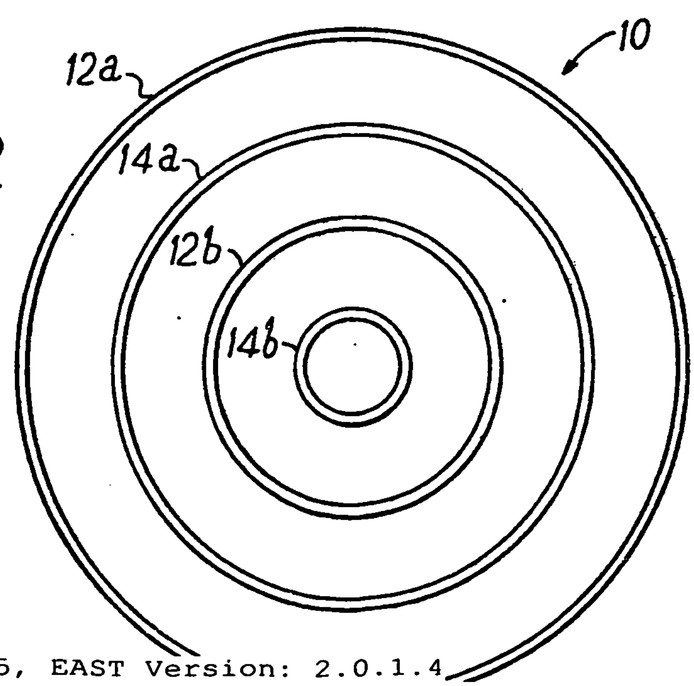


FIG. 2



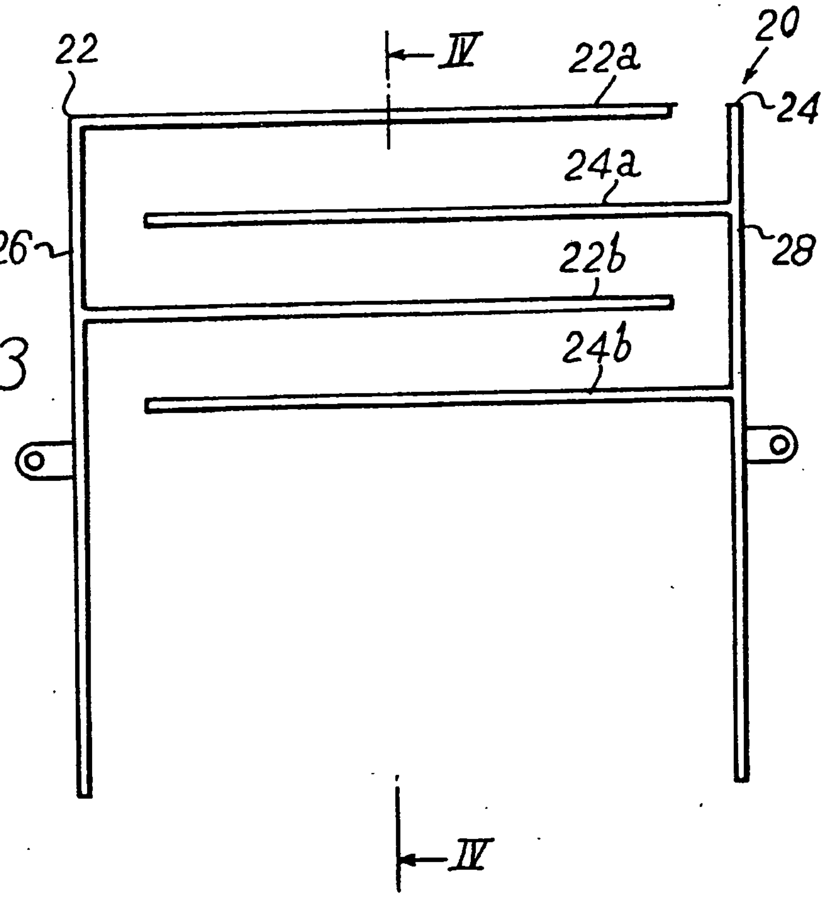


FIG. 3

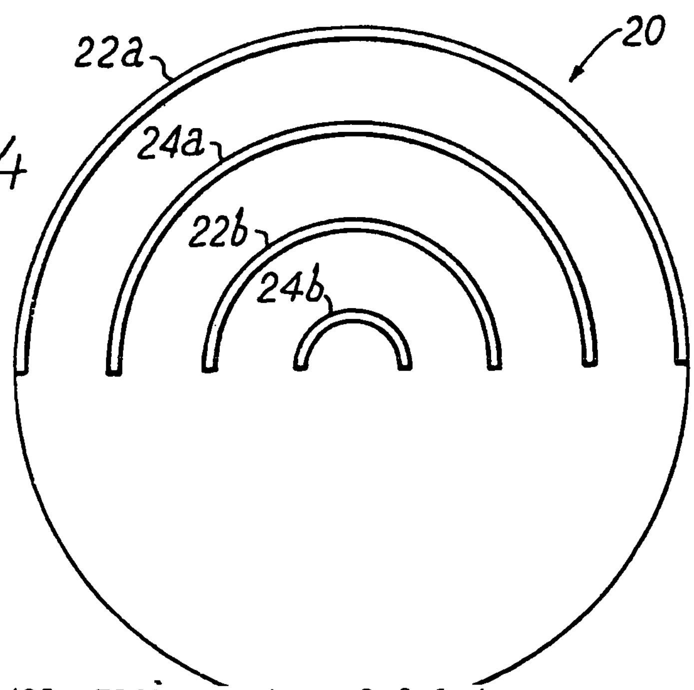
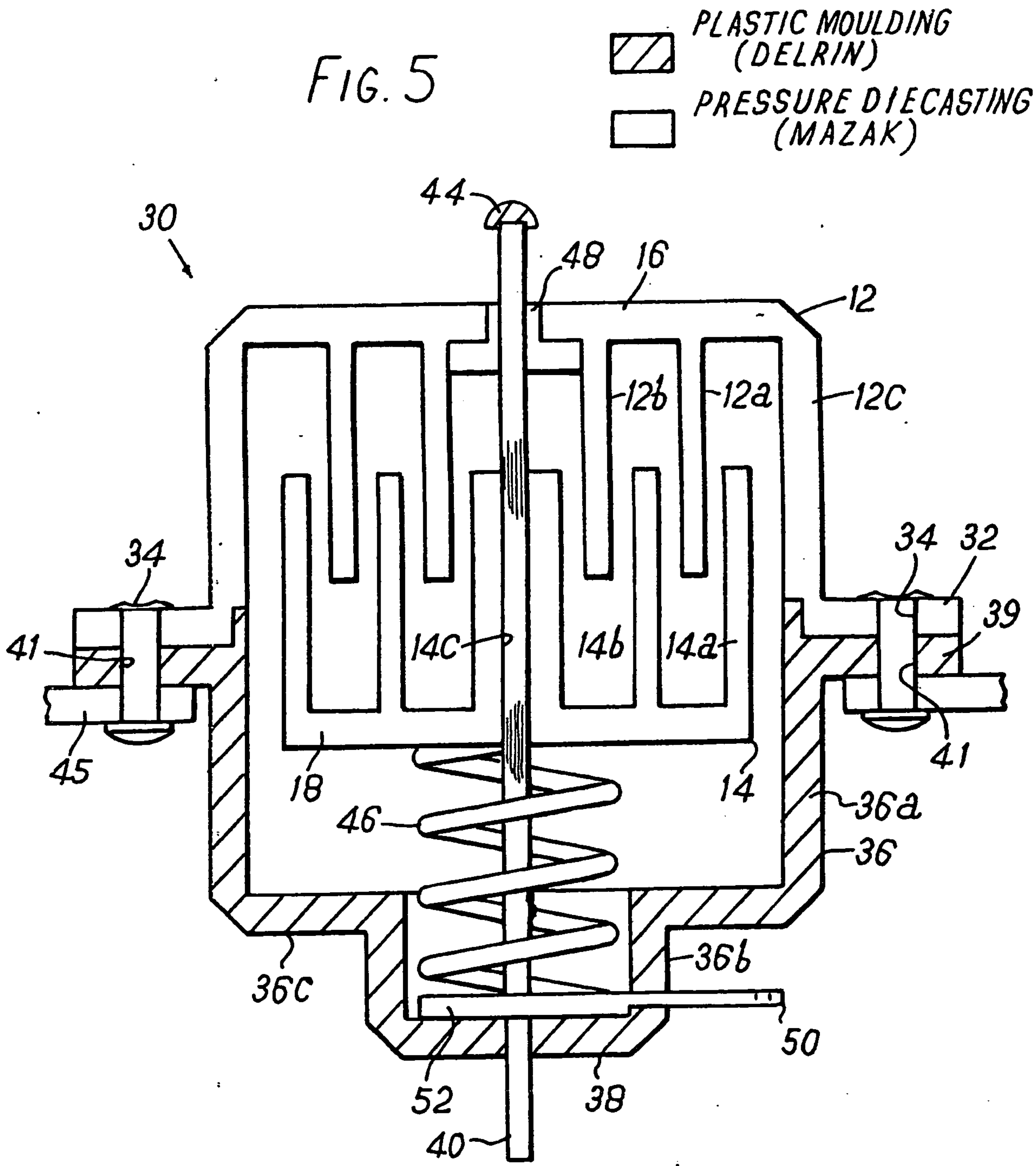


FIG. 4

FIG. 5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PRESSURE DIECASTING (MAZAK)
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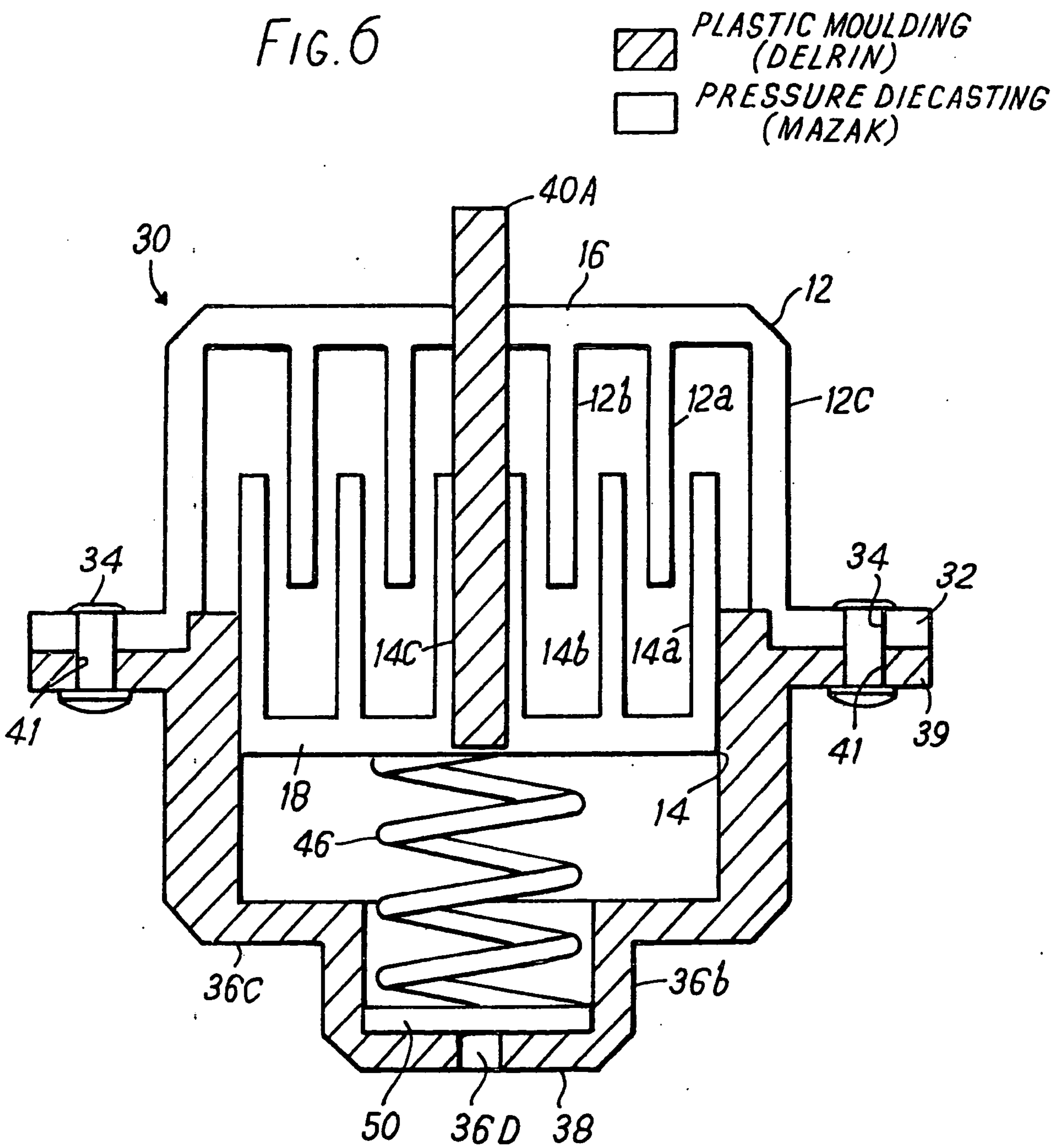
12a
12C
34
32
39
41
14C
14b
14a
45
18
14
46
36a
36
36b
36C
50
52
38
40

(?

FIG. 6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PRESSURE DIECASTING
(MAZAK)
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36b
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36D
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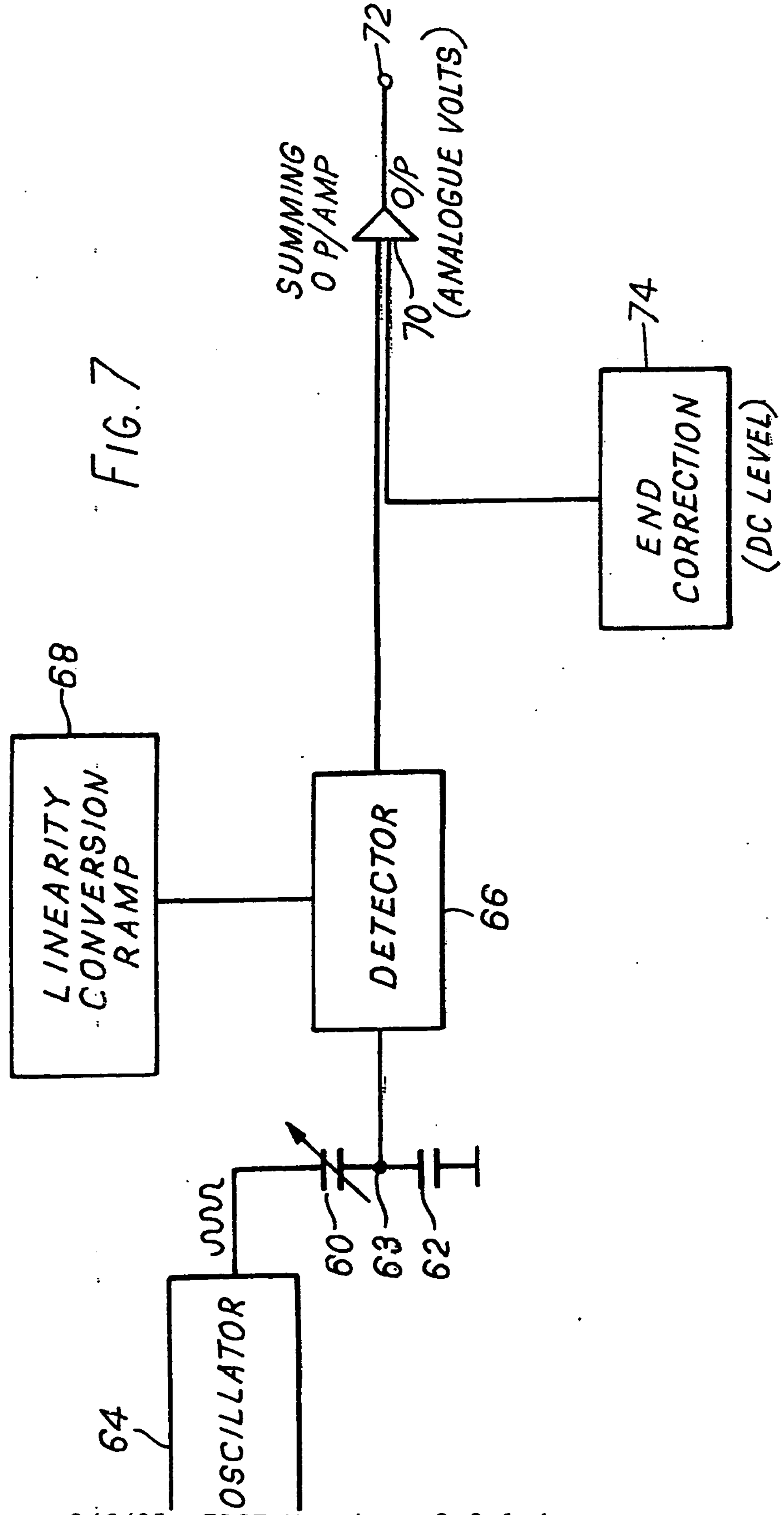
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O/P
(ANALOGUE VOLTS)
70
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END
CORRECTION
(DC LEVEL)
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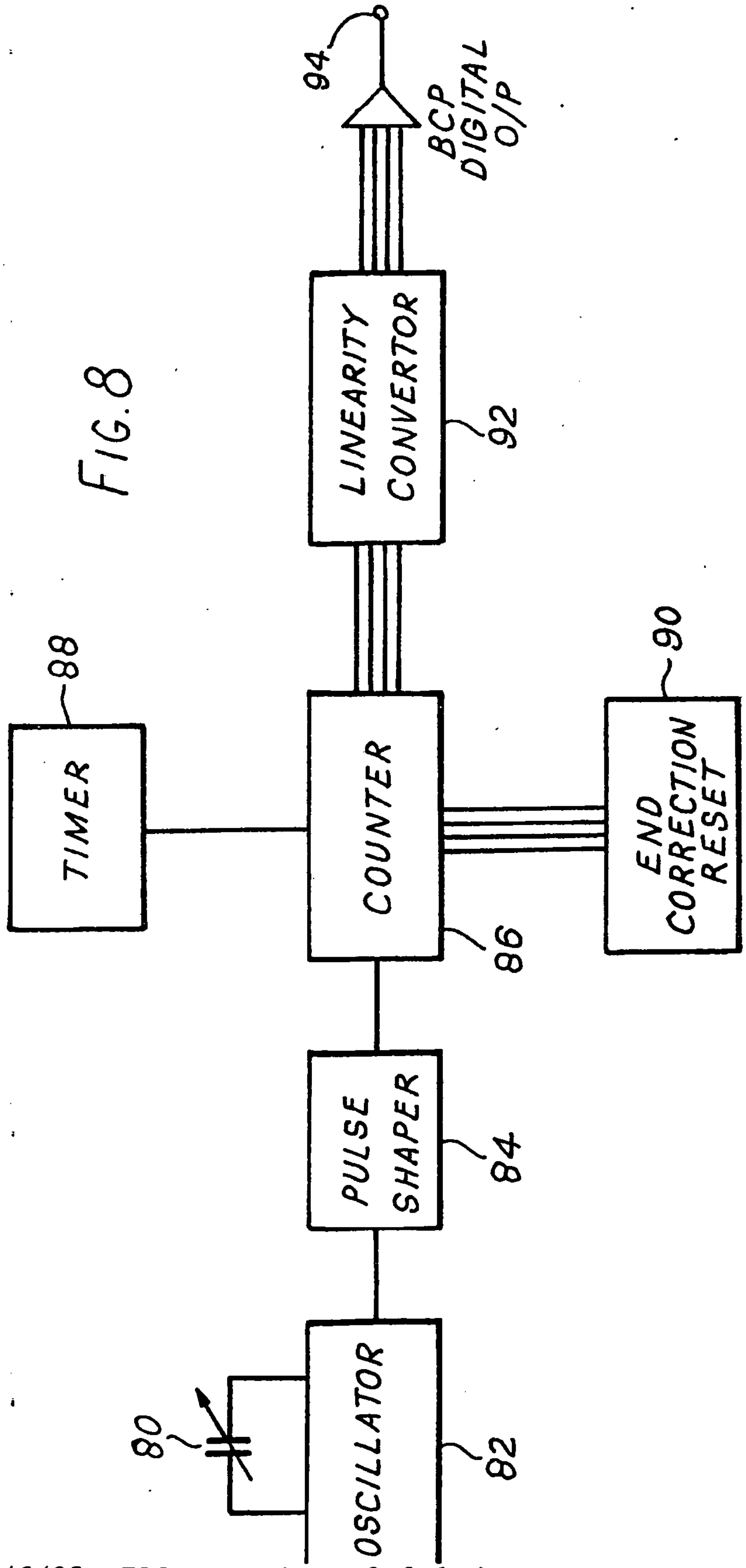
LINEARITY
CONVERSION
RAMP
DETECTOR
66
60
63
62
OSCILLATOR
64

FIG. 7

FIG.8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BCP DIGITAL O/P
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COUNTER
86
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END CORRECTION RESET
PULSE SHAPER
84
80
OSCILLATOR
82

SPECIFICATION

Improvements in displacement transducers

This invention relates to displacement transducers in which relative movement between two parts of the transducer results in a change in an electrical parameter, such as capacitance. The relative movement can be, for example, linear or rotary. The change in the value of the electrical parameter is preferably dependent upon the magnitude of the displacement and can have a linear or non-linear relationship but generally it is required that the relationship be pre-determinable or determined empirically.

Such transducers are well known and the electrical quantity may be derived from, for example, a piezo-electric crystal or an inductive or resistive or capacitive component.

In many applications a plurality of substantially similar transducers are used in the same system and their electric output signals are interrogated sequentially by an electronic measuring device so that the signals are recorded and/or used to control operation of the system. As the signals are all measured by the same measuring apparatus, it is important that the transducers have the same law and that any variations in their law due to changes in environmental conditions, their age and the amount of their use be consistent within reasonable tolerance ranges. The production of transducers with the above characteristics is possible but becomes increasingly more expensive with reduction in the tolerance range required.

Furthermore, with the rapid development of electronic control apparatus, computers and the like, with a concomitant reduction in their cost, the application of systems, such as microprocessor systems using more and more transducers is becoming commonplace and there is thus a need for relatively inexpensive transducers.

When, considering the various displacement transducers available, the piezo-electric device has the disadvantage that force must be applied to it to produce the piezo-electric voltage change. The inductive device requires a coil which must be moved in a magnetic field and the production of a coil is expensive and a sophisticated circuit is required to maintain a constant magnetic field, and the resistive device has the advantage that the resistive element is subjected to wear as a contact is moved therealong.

The present invention provides a method of manufacturing a plurality of capacitative displacement transducers all having consistent characteristics, comprising the steps of preparing a die-casting mould for the production of capacitor plates to be included in said transducers, pressure die casting a plurality of capacitor plates, each from the same mould, and assembling the die cast plates into respective transducers whereby all said transducers have similar characteristics as defined by the shape and dimension of the initially prepared mould.

Preferably, each transducer comprises two cooperating capacitor plate elements and two corresponding moulds are prepared, from each of which a corresponding one of the plate elements for each of the transducers is produced.

By using pressure die-casting for the manufacture of one or both of the capacitor plates it is possible to reproduce large quantities which are consistent in quality. Preferably the law of change in capacity with displacement is linear but other laws are quire acceptable particularly now that electronic circuits can be designed to convert the actual law to the desired law. The cost of a die-casting mould can be quite high but once designed and manufactured, it is possible to produce a large number of die-cast plates relatively inexpensively.

The moulding operation is simplified when each of said capacitor plate elements comprises one or more cylindrical or part-cylindrical plates, and said plate elements are mounted in the finished transducer with the respective cylindrical plates arranged coaxially with respect to one another for relative movement. This enables each of the moulds to be provided with surfaces defining said cylindrical or part-cylindrical plates which taper axially towards free ends of the cylindrical plates to provide a mould release angle. Advantageously the mould release angles of the respective plate elements are arranged to be complementary so that the dielectric gap between the respective plate elements is defined between mutually parallel surfaces.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 shows a cross-sectional view of part of one embodiment of a linear displacement transducer according to the invention,

Fig. 2 shows a view of the transducer of Fig. 1 taken on the line II-II,

Fig. 3 shows a cross-sectional view of part of another embodiment of a rotary displacement transducer according to the invention,

Fig. 4 shows a view of the tranducer of Fig. 3 taken on the line IV-IV,

Fig. 5 shows a cross-sectional view of another linear displacement transducer according to the invention,

Fig. 6 shows a view similar to that of Fig. 5 of a further embodiment of linear transducer according to the invention,

Fig. 7 shows a block diagram of an analogue electrical circuit for use with any of the transducers of Figs. 1 to 4, and

Fig. 8 shows a block diagram of a ditigal electrical circuit for use with any of the transducers of Fig. 6.

Referring now to Figs. 1 and 2, there is shown the capacitive element 10 of a linear displacement transducer.

The capacitive element 10 comprises a first plate 12 and a second plate 14. The first plate 12 comprises two coaxial cylinders 12*a*, 12*b* joined at one end to a circular plate 16 to form a rigid plate struc-

The drawings originally filed were informal and the print here reproduced is taken

ture. Similarly, the plate 14 comprises two coaxial cylinders 14*a*, 14*b* joined at one end to a circular plate 18 to form a rigid structure. One of the plates 12, 14 is mounted on bearings (not shown) so that it can be moved linearly relative to the other along their mutual axis, the cylinders being so dimensioned that their relative radial spacings are equal. Air is used as the dielectric between the capacitor plates 12, 14 and, as is well known, the capacitance between the plates is dependent upon the effective surface area of the plates and the dielectric constant of the intervening medium, in this case air, and inversely proportional to the distance between them. Thus, as the plates 12 and 14 are moved apart linearly along their mutual axis, the capacitance between them is reduced and this change in capacitance with displacement can be measured to provide an indication of the magnitude of the displacement.

Such a capacitor plate could be manufactured by machining them from a solid workpiece but this would be time consuming and expensive.

However, we have found that we can manufacture the plates by pressure die-casting which facilitates high production rates at low cost. In the drawing we have drawn the cylindrical parts with straight lines although in a practicel device they will taper slightly towards their open ends because the moulds will be tapered in a complementary manner to allow a small release angle. However, this does not detract from the utility of the capacitive element and any non-linearities can be compensated in the electronic circuit. A suitable release angle may be based on a taper of about 1.5×10^{-3} mm/mm length and for capacitive element having external dimensions when closed of about 3 cm in length and 3 cm diameter the capacitance range may be up to about 100 pF. It should be noted that with the illustrated cylindrical configuration of the capacitor plates the axial taper due to the mould release angle is equal and opposite for the two sets of plates and thus the dielectric gap between the plates is defined between facing surfaces of the plates that are mutually parallel.

Referring now to Figs. 3 and 4, there is shown the capacitive element 20 of a rotary displacement transducer.

The capacitive element 20 comprises a first plate 22 and a second plate 24. The first plate 12 comprises two coaxial semi-cylinders 22*a*, 22*b* joined at one end to a circular plate 26 to form a rigid plate structure. Similarly, the plate 24 comprises two coaxial semi-cylinders 24*a*, 24*b* joined at one end to a circular plate 28 to form a rigid structure. The plate 24 is mounted on bearings (not shown) so that it can be moved rotatingly relative to the plate 22 around its axis, the semi-cylinders 22, 24 being so dimensioned that their relative radial spacings are equal. Air is again used as the dielectric between the capacitor plates 22, 24.

As the plate 24 is rotated relative to the plate 22, the capacitance of the element 20 changes and again this change in capacitance can be used to provide an indication of the rotary displacement of the plate 24 and a member whose rotary movement is to be monitored which is rigidly secured to it.

Referring now to Fig. 5 there is shown a cross-sectional view of an embodiment of a linear displacement transducer 30 embodying a capacitive element 10 similar to that described with reference to Figs. 1 and 2.

In this device the plate 12 is provided with a third, outer cylinder 12*c* which extends from the periphery of the circular member 16 and is provided at its distal end with an outwardly extending flange 32 provided with a plurality of symmetrically disposed apertures 34. The members 16 and 12*c* also form one part of a housing for the transducer 30. The other part of the housing is formed of a moulded plastics member 36. The member 36 has a first generally cylindrical part 36*a* and a second generally cylindrical part 36*b* joined by part 36*c*, the remote end of part 36*b* being closed by an end wall 38 having an aperture formed therein for receipt of a spindle 40 journalled therein. The open end of cylinder 36*a* is provided with an outwardly extending flange 39 having a plurality of symmetrically disposed apertures 41 therearound corresponding to the aperatures 34. The two housing parts are secured together by fastening means 43 which extend through the apertures 34 and 41. The fastening means can also be used to secure the transducers to a mount 45 as shown.

The spindle 40 passes through and is rigidly connected to an aperture 14*c* in plate 14 and then passes through a journalled aperture 42 in the end plate 16 of plate 12. The end of spindle 40 protruding through aperture 42 is terminated in a hemispherical member 44. Thus a force applied to the member 44 and having a component of force parallel to the mutual axis of plates 12, 14 will cause a linear displacement of the plate 14 with respect to plate 12. If the spindle 40 is connected permanently to a member whose linear motion is to be monitored then the position of the plate 14 will be automatically and continuously adjusted with respect to plate 12.

In some applications it may be required to bias the plate 14 to a datum positon. In the example of Fig. 5 a compression spring 46 is provided which is arranged coaxially about spindle 40 and has one end abutting the external face of member 18 and the other end abutting the internal face of end wall 38. Thus in the absence of a downwardly (in the figure) directed force applied to spindle 40, the spring 46 biases the plate 14 upwardly into the closed, maximum capacitance value, position of the capacitive element.

The spindle 40 is journalled in end wall 16 in a bearing 48 of an insulating material and an electrical connection to plate 14 can be taken from a terminal 50 which forms part of a journal 52 on end wall 38. The electrical connections to the other plate 12 can be taken from a convenient part of the end wall 16 or flange 34.

Fig. 6 shows a further embodiment of transducer which corresponds closely to that of Fig. 5, and in which like parts are illustrated with like reference numerals. In the embodiment of Fig. 6, the mounting of the plate 14 is simplified in that the spindle 40 of Fig. 5 is replaced by a shaft 40A of insulating material projecting forwardly through the circular member 16 and journalled directly therein, and the thickness

of the cylindrical part 36A is increased so that the plate 14 is slidingly supported therein. This avoids the need for a journal 52, although a simple disc forms terminal 50 to which a connecting lead may extend through an aperture 36D. The shaft 40A may be moulded from synthetic plastics material in a similar manner to the housing element 36, being dimensioned to be a force fit within the bore 14C. The construction of the transducer is thus extremely simple and the number of components is minimised.

Thus there have been described four embodiments of a capacitor and displacement transducer in which both plates are formed by a pressure die-casting technique. While generally cylindrical or semi-cylindrical capacitor plates have been described the plates can, of course, be of any suitable shape which can be produced by pressure die-casting techniques.

The capacitor plates can be of any suitable material capable of being cast and one suitable material is a zinc alloy known as MAZAK (Trade Mark). The housing part 36 can be of any suitable non-conductive material and may be a plastics material such as DELRIN (Trade Mark) – which is believed to be an acetal polymer.

Referring now to Fig. 7, there is shown a simple block diagram of a circuit for use with a transducer according to the invention.

In the drawing the transducer is shown as a variable capacitor 60 which with a fixed capacitor 62 forms a divider circuit coupled between the output of an oscillator 64 and signal ground. The amplitude of the oscillatory signal at the junction 63 of the capacitor 60 which the capacitor 62 will be dependent upon the capacitance of capacitor 60 and hence the displacement, linear or rotary as the case may be, of a member to be monitored which is coupled to the movable plate of capactir 60. The junction 63 is coupled to the input of a detector circuit 66 which converts the oscillatory signal to a unidirectional signal having a magnitude dependent upon the amplitude of the oscillatory signal applied to its input.

If necessary a lineariser circuit 68 can be provided to ensure that the output of the circuit 66 is linearly dependent upon the displacement of the transducer.

The output of circuit 66 is coupled through an operational amplifier 70 to an output terminal 72. Non-linearities of capacitance of capacitor 60 may occur at the limits of travel and these could be compensated by a d.c. correction signal generated by a circuit 74 and applied to the summing input of amplifier 70.

The output terminal 72 can be coupled to a measuring instrument such as a digital voltmeter (not shown) and to control operation of the member being monitored.

Referring now to Fig. 8, there is shown a simple block diagram of a circuit for use with a transducer according to the invention and arranged to provide a digital output.

In this circuit, the transducer is depicted as a variable capacitor 80 which forms part of the frequency-determining part of a variable frequency oscillator 82. The output of the oscillator 86 is coupled to the input of a pulse-shaping circuit 84 which provides a square wave output to the count input of a counter 86. The counter 86 has another input coupled to a reset/timer circuit 88 which periodically resets the counter to a datum value, for example zero, and then allows the counter to count input pulses for a predetermined period, at the end of which period the number in the counter is dependent upon the frequency of oscillator signal and hence on the displacement of the transducer.

As with the circuit of Fig. 7 an "end correction circuit" 90 may be provided and in the case of a binary coded decimal (BCD) counter the error correction signals can be BCD numbers which would be added to or subtracted from the count in counter 86 as required.

The output of the counter 86 is coupled through a linearising circuit 92 to provide a BCD output signal at terminal 94 which can be recorded and/or used to control the position of a member coupled to the transducer.

CLAIMS

1. A method of manufacturing a plurality of capacitative displacement transducers all having consistent characteristics, comprising the steps of preparing a die-casting mould for the production of capacitor plates to be included in said transducers, pressure die casting a plurality of capacitor plates, each from the same mould, and assembling the die cast plates into respective transducers whereby all said transducers have similar characteristics as defined by the shape and dimensions of the initially prepared mould.

2. A method as claimed in Claim 1, wherein each transducer comprises two cooperating capacitor plate elements and two corresponding moulds are prepared, from each of which a corresponding one of the plate elements for each of the transducers is produced.

3. A method as claimed in Claim 2, wherein each of said capacitor plate elements comprises one or more cylindrical or part-cylindrical plates, and said plate elements are mounted in the finished transducer with the respective cylindrical plates arranged coaxially with respect to one another for relative movement.

4. A method as claimed in Claim 3, wherein each of said moulds is provided with surfaces defining said cylindrical or part-cylindrical plates which taper axially towards free ends of the cylindrical plates to provide a mould release angle.

5. A method as claimed in Claim 4, wherein the mould release angles of the respective plate elements are arranged to be complementary so that the dielectric gap between the respective plate elements is defined between mutually parallel surfaces.

6. A method as claimed in Claim 1, substantially as described herein.

7. A displacement transducer when made by the method of any one of Claims 1-6.

8. A capacitative displacement transducer comprising at least one capacitor plate element produced by pressure die casting.

9. A transducer as claimed in Claim 8, comprising two cooperating capacitor plate elements, each produced by pressure die casting.

10. A transducer as claimed in Claim 9, in which each of said capacitor plate elements comprises one or more cylindrical or part cylindrical plates, said plate elements being mounted for relative movement with the respective cylindrical plates arranged coaxially to one another.

11. A transducer as claimed in Claim 10, in which each said plate element comprises a plurality of part cylindrical plates arranged concentrically in facing relationship, the respective plate elements being mounted for relative rotation about a common central axis to enable variation of the area of overlap of interleaved plates of the respective elements.

12. A transducer as claimed in Claim 10, in which each of said capacitor plate elements comprises a plurality of spaced-concentric cylindrical plates extending in cuplike fashion from a common base wall, said plate elements being mounted for relative axial movement along a common central axis to enable the free ends of the cylindrical plates to be variably interleaved with one another.

13. A transducer as claimed in Claim 11 or 12, wherein each of said plates is tapered axially towards its free end, the angles of taper of the respective plate elements being complementary so that the facing surfaces of over-lapping plates are mutually parallel.

14. A transducer as claimed in Claim 12, wherein a transducer housing is defined by the outer cylindrical plate and base wall of the plate element of larger external diameter, in combination with a complementary cup element formed of electrically insulating material and within which the plate element of smaller diameter is mounted for axial movement.

15. A transducer as claimed in Claim 14, wherein the said plate element of smaller diameter comprises a central bore supporting a shaft of electrically insulating material which is arranged to project through and to be slidingly received in a bore in the base wall of the said larger plate element, whereby the end of said shaft projects from said housing to form a sensing abutment of the transducer.

16. A transducer as claimed in Claim 15, wherein the said cup-element of insulating material comprises a cylindrical inner wall arranged to support the outer cylindrical plate of the said smaller plate element for axial sliding movement.

17. A transducer as claimed in Claim 16, wherein the said shaft and said cup-element are formed as mouldings of synthetic plastics material.

18. A capacitative displacement transducer substantially as described herein with reference to any one of Figs. 1 to 5 of the accompanying drawings.

19. A capacitative displacement transducer substantially as described herein with reference to Fig. 8 of the accompanying drawings.

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